The third instrument, and the one which is shown attached to the ends of the shaft in Figs. IX. and X., is the one which has been found to most satisfactorily fulfil the conditions required of it. It is extremely simple in design and entirely automatic in its readings—giving

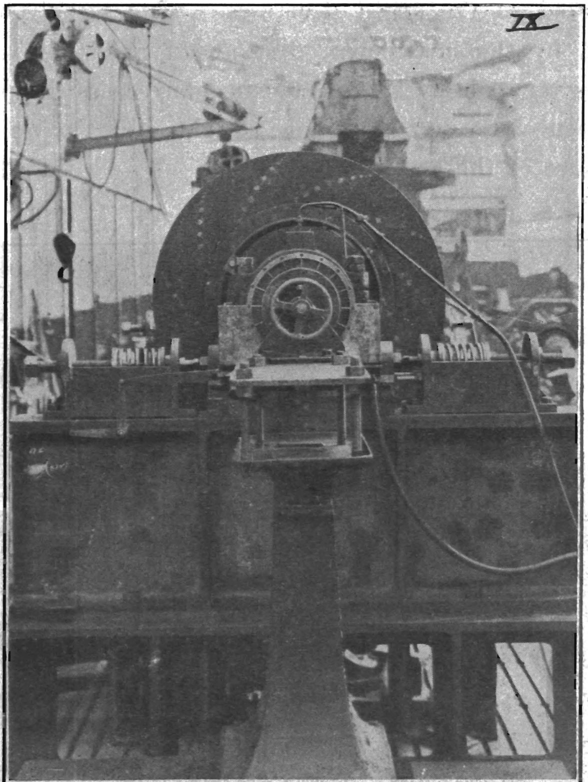

Fig. 9

very closely and frequently the precise position and the exact extent of the maximum amplitude. This is done whilst the speed is being either accelerated or decelerated, so that all that is now necessary to obtain a reading is to start up the rotor—letting it accelerate till the period of maximum amplitude is reached, shut off the power, and, when the rotor has stopped, take a reading. Then readjust the instrument to zero, restart the rotor in the opposite direction, and take another reading, or accelerate the rotor to a point beyond the maximum vibration, shut off the power, and let the instrument be operated as the speed decreases. The mean position given by the instrument, first ahead and then astern, shows very closely indeed, and in many cases the precise position of the out of balance weight, and also an exact measure of the amplitudes.

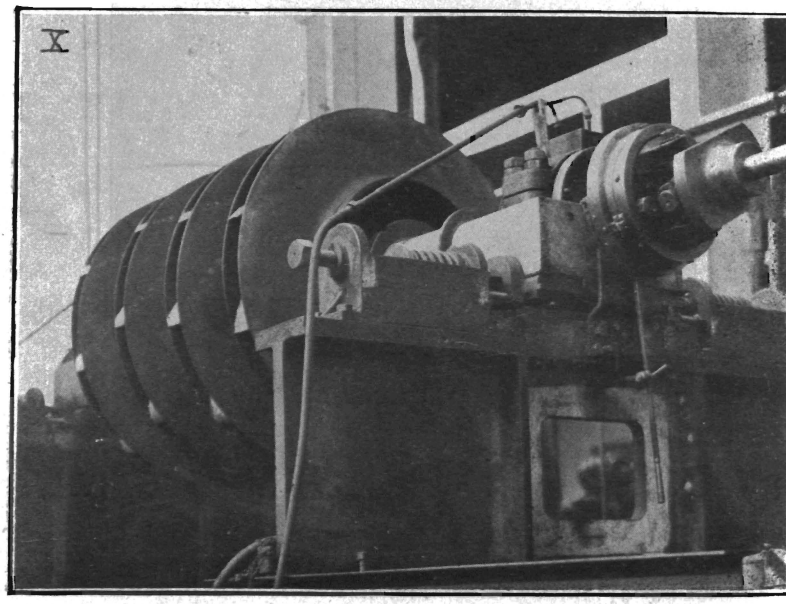

Fig. 10

We are not concerned with recording the exact speed at which the maximum vibration occurs; all we want is that the point at which that maximum occurs—going ahead or astern—shall be recorded relative to the rotor.

DYNAMIC BALANCING

DIAGRAMATIC ARRANGEMENT OF GEAR SHEWING SPIDERS IN POSITION ON ROTATING MASS BEING BALANCED, ONE AT EACH END

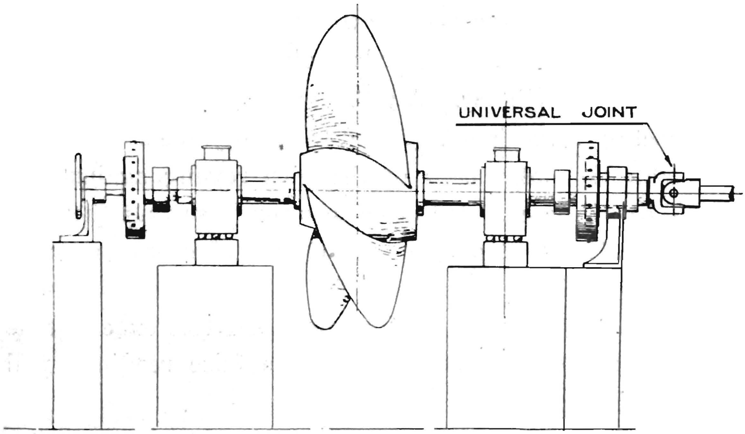

FIG. XI

DYNAMIC BALANCING

"SPIDER" AUTOMATIC RECORDING GEAR

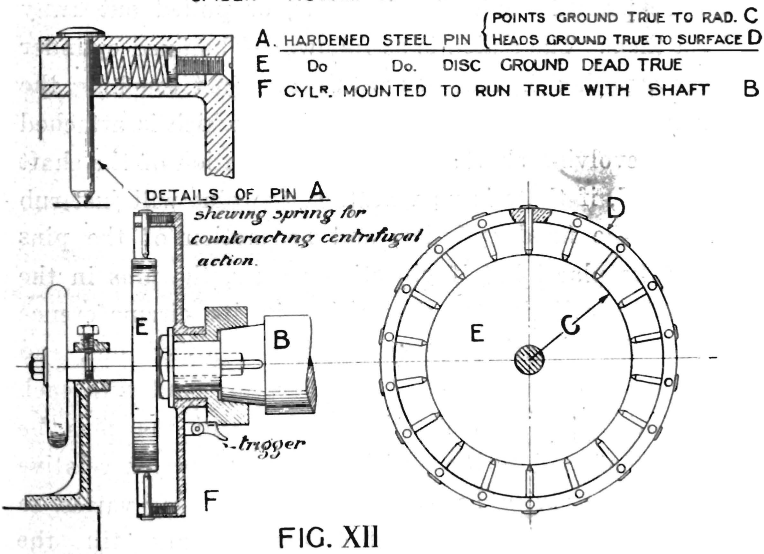

FIG. XII

Figs. XI. and XII. are diagrammatic sketches of it. It consists of a short cylinder attached to the revolving shaft, and through the cylinder pass a number of hardened steel pins as shown, which pins are arranged so that they can move outwards radially through the thickness of the cylinder. All the inner points of the pins projecting inwards are ground to exactly the same circle, and all the outer ends of the pins resting against the surface of the cylinder are also ground, so that they are all exactly proud of the cylinder's surface to the same extent. It is essential that the cylinder, with its pins, which we have called the "spider," shall be exactly true with the revolving shaft, otherwise false readings will be obtained.

A second short hardened steel cylinder or disc ground true to the same diameter as the inner points of the pins is erected on a fixed base in line with the first cylinder. This second cylinder is made to slide axially, so that it can be pushed in under the pins, or pulled out away from them. The action is as follows:—The fixed cylinder is, say, pushed in and lies within and just touching the inner points of the pins on the spider, which is attached to the revolving shaft; clearly when rotation of the shaft is started, if there is no vibration, the pins will just rub around the fixed cylinder, and no motion of the pins will take place, but if vibration occurs, the pins in the revolving cylinder at that point in its circumference where the vibration occurs will be pushed out, and pushed out to the extent of the vibration, and with each succeeding increase of vibration so will the pins be pushed out, and as the position of the vibration relative to the rotor varies, i.e., as the angle of the lag varies, so will the pins be pushed out correspondingly till the period of maximum vibration is reached and passed, when the pins recording that maximum will no longer be affected. The motion may then be stopped, and the amount the pins have been pushed out can be measured, and the position of the highest pin can be located. A slight eccentricity between the setting of the two cylinders is immaterial; if they are not in line, the only result will be that as the spider revolves it will act on all the pins equally to the extent of the eccentricity. In the vertical motion type of balancer, the centre of the revolving shaft was, owng to the addition or subtraction of weights, constantly altering, necessitating the stationary disc being readjusted to suit. This obviously took time, whereas, with the horizontal gear, once the centres are adjusted, they are correct for all time on the one job. Owing to the variation of the angle of lag as the speed alters, it will be found that all the pins are pushed out gradually increasing from a minimum to the maximum.

Two of these instruments are used—one at each end of the apparatus being balanced; that at the driven end —having to allow for the driving shaft—is of annular form, so as to surround and be clear of that shaft, and give room for it to vibrate. This is shown in Fig X.

When the out of balance is considerable, the position of the pin that is furthest out can be readily detected by the eye, but when it is small it is necessary to measure the height of the pins with some form of micrometer. A very handy form is a clock micrometer, which is quickly read, and gives readings to 1/1000th of an inch. By the use of this micrometer the necessary magnification of the actual amplitude of vibration given by the pins is obtained.

We have here, then, an instrument which gives both the position of the out of balance weight, and at the same time gives a measure of the extent of the maximum vibration. It does this very simply, very rapidly and automatically, and also takes account of the instant at which the maximum amplitude occurs, without any necessity for an observer to be watching to note when this period occurs.

The authors of the article in "Engineering" referred to, and also Comr. Cleary in his paper, both used the same, or practically the same, means of reading the amplitude of vibration and the angle of lag, which was by means of a spot of light passing through an involute slot cut in a disc attached to the end of the revolving shaft, and then magnifying the motion by mirrors, and noting the position of the spot of light on a screen. This method appears to have given the respective authors satisfaction, but it does not give a permanent record, and is applied to one end only. I have always thought that we should be able to obtain a record of what is happening at both ends simultaneously, and have worked with that end in view. I cannot help thinking that this is the correct way, and my views have been upheld by the results we have obtained with the two spiders, as we have found that not only are the amplitudes of vibration different at either end, but also their position; e.g., when we get a case of out of balance as illustrated in Fig. V. of my former paper, we found, as anticipated there, that the opposite ends were moving in opposite directions, and also, curiously enough, the angles of lag were different.

In my opinion, and in spite of possibly repeating myself, I maintain that it is just when the amplitude is at its maximum we want to obtain a record of it, and a record of the position of that throw relative to the rotor.

If we can obtain these, which this "spider" instrument just does, we obtain all the information necessary to determine the position of the out of balance weight. I cannot at present affirm, from experiments we have made, that the extent of that vibration is any guide as to the amount of that out of balance weight, as, with a balanced rotor put out of balance by attaching known weights in known positions, some very extraordinary results have been obtained, which will be referred to later. Now that we have the spiders fitted at both ends of the balancing apparatus, and have been able to obtain reliable records of what has been occurring, which, in the absence of such means, we were previously unable to accurately obtain, we have discovered a number of most curious anomalies, and, primarily, any results or deductions we hoped to have concluded from a number of experiments we had made with a series of known weights and springs, have been entirely obscured by the complications created by the method of driving the rotor.

It would appear that the flexible shaft with hook joints has no disturbing effect so long as there is no vibration, but as soon as a vibration is set up, the driving gear, by reason, we think, of its whipping action, seriously upsets the motion. This action, unfortunately, occurs when accelerating, and when the power is shut off and the rotor is slowing down, as a reverse action is set up by reason of the rotor driving the motor.

In our work considerable power is required to drive the rotors or propellers, and it would not be possible to adopt the method shown in Fig. I., viz., that employed for balancing the armatures. For one thing, the belt would have to be heavy, and, as proved by us when we tried a similar drive with a chain, whipping actions are set up, which completely upset the balancing trials. Nor would the method adopted by Comr. Cleary, vide Fig. II., be satisfactory. With the flexible shaft and hook joints, the action is to accentuate the vibration at the driven end, whereas with Comr. Cleary's drive a little consideration will show that it would probably tend to decrease the vibration, and that would be just as unsatisfactory. These actions of the driving gear upset the amplitudes of vibration, but do not apparently greatly disturb the readings which give the position of the out of balance, but the upsetting of the amplitude is sufficient to entirely mislead the balancer in judging at which end the out of balance weight is really situated. We have, therefore, come to the conclusion that some other means of driving the rotor must be devised, which will not create these disturbances. Another conclusion we have come to is that, failing to devise such a method, we shall have to introduce a clutch such that the rotor may be disconnected entirely, and be free to revolve under its own forces. We shall have to first speed up the rotor to beyond the period of maximum vibration, then declutch, and whilst the rotor is slowing down, take readings of the amplitude and position of the out of balance weight with the spider instruments, when it is hoped we shall get what we think we ought to get, viz., that the position of the out of balance weight, relative to the fore and aft direction, will be given by the amplitude of the vibrations at either end.

We have also tested springs of different length and strength, but, owing to the upsetting action of the driving gear, we are unable to draw any definite conclusions. So far, it would appear, as anticipated, that short springs operate at a higher speed, but one most astounding anomaly has arisen, and that is with a spring $6\frac{1}{4}$ in. long of $\frac{1}{2}$ in. diameter steel, of a compression strength of

270 lbs. per inch, and with weights (A) of 2 lbs. in line at the extreme ends of the balanced rotor under trial, an amplitude of .05 in. was obtained at the driven end and .06 in. at the free end, whereas, with a spring of the same dimensions, except that it was of ¾ in. steel and a strength of 1145 lbs. per inch compression, we got amplitudes of .23 in. and .185 in. respectively—a most, at present, unaccountable result. Again (B), with 2 lbs. at each end, but at 180 deg. with each other, just the opposite results were obtained. With the light spring the readings were .142 and .142, and for the stiff spring .09 and .08 respectively. Again, although the springs were of the same length, and although the amplitudes differed so much, the speed at which the maximum occurred was about the same for each spring in each case, but that of the stiff spring was 195 and of the light spring 175 revs. per minute.

One further illustration—two experiments were made—one with a single out of balance weight of 2 lbs. at one end only, with the same springs in each test, the first one with the weight at one end, and the second one with the weight at the other end, the records are as under:—

	DRIVEN END.				FREE END.			
	Maximum amplitude.		Angle of lag.		Maximum amplitude.		Angle of lag.	
	Ahead.	Astern.	Ahead.	Astern.	Ahead.	Astern.	Ahead.	Astern.
C. 2lb. weight at free end ...	·06	·095	275°	270°	.105	.09	125°	145°
D. 2lb. weight at driven end	.06	.075	130°	115°	.055	.09	285°	265°

Note how the amplitude at the driven end is about the same in both cases, yet one would expect it to be greater in D than C, whereas the reverse is the case. This is probably caused by the whipping action of the driving gear. Note the extraordinary variation in the angles of lag, and yet these angles give the position of the out of balance weight very closely. The error is only half the difference between the angles of lag ahead and astern.

These experiments were made with a plain cylindrical mass, viz., a flywheel, weighing 1.86 tons, which could not introduce any possible fan action like a propeller.

The angles of lag with the two different springs referred to above varied, in one instance, in an extraordinary way, as shown hereunder:—

	Light Spring.		Stiff Spring.	
	Free end.	Driven end.	Free end.	Driven end.
C.	147°	200°	140°	155°
D.	120°	125°	112°	325°

In another case, with condition B, we had an angle of lag of 360 deg.

In the majority of cases the lag is about 140 deg., but varies from about 75 deg. to 360 deg., in other words, the out of balance weight has swung round well towards the opposite diameter, and even beyond, before its influence is felt on the revolving mass—causing it to swing. These results in themselves are remarkable.

In spite of these anomalies and disturbing factors, it has been possible to effect the dynamical balancing of rotors, but it must be admitted that in the past there has been a good deal of trial and error before the proper position of the out of balance has been located, and a good deal has also depended upon the experience and skill of the balancer. I am, however, still hopeful of being able to reduce the problem to a more exact and precise basis. We have learned a good deal, but the more the subject is investigated the more complex it appears, and the more one realises how really puny is human intellect in being able to foretell what is really going to happen when certain apparently simple forces are put into operation.

Following up again the subject matter of my former paper, wherein I described the reduction in vibration in ships after the propellers had been dynamically balanced, I may state that since then the propellers of two vessels well known in this country, viz., the "Loongana" and the "Niagara," have had their propellers dynamically balanced by us. Both these vessels belong to the Union Steam Ship Company of New Zealand, who had the enterprise to try the experiment. In the latter there are three screws—the two outer screws are driven by reciprocating engines at 80-85 revs. per minute, and the centre screw by a low pressure turbine at 200-220 revs. per minute. This propeller is 10 ft. in diameter and weighs 4 tons. In the "Loongana" there are three screws, all turbine driven, and run at about 530 revs. per minute, these propellers are 5 ft. 2 in. in diameter, and each weighs 7¼ cwt. In the "Niagara" only the turbine driven screw was dynamically balanced. In the case of each of these vessels, the Company has written to me to say that there has been a material reduction in vibration. This is all the more worthy of notice in the case of the "Niagara" on account of two facts—(1) That only one screw out of the three was balanced, and (2) the comparatively low speed of the propeller compared with the cases I formerly quoted, viz., about 500 revs. per minute in the cruiser, and between 800 and 900 in the Destroyers.

This remark is specially made, as it has been argued that the dynamical balancing of propellers running at low speeds would not be worth while, but I venture to think the "Niagara" is a remarkable example of the value of thus balancing. I venture to quote the appended letter from the Company, dated 5th June, 1919:—

UNION STEAM SHIP CO. OF NEW ZEALAND LIMITED,

Sydney, 5th June, 1919.

J. J. King-Salter, Esq., General Manager,
Naval Dockyards, Cockatoo Island, Sydney.

Dear Sir, R.M.S. "Niagara"—Combination Engines. Wing Engine Reciprocating, Centre L.P. Turbine.

In reference to the Manganese Coy's Propeller for this steamer, which was bored out and dynamically balanced at the Naval Dockyards in November 1917, and fitted on the "Niagara" at the end of December 1917, I am pleased to say the results have been very satisfactory from same. The vibration is considerably reduced. The propeller shows the same efficiency as the original one made by the Manganese Bronze Co.

The revolutions from the Reciprocating Engines vary from 85 to 88 per minute, and the Turbine propeller from 210 to 220 per minute.

The Chief Engineer wrote me fiom Auckland, in reference to this propeller in the following terms:

"January 1918, Auckland. The vibration records were taken uuder very similar conditions as regards weather. The records show less vibration, of course there is more difference felt than recorded. The pipes under the Promenade Deck, which used to rattle badly at times were quiet, also steering house doors and loose fittings, such as window-frames, bad fitting rails etc. The second class accomodation, Captain's room too, are also much improved. Of course the conditions are the best, when we get bad weather and oil bunkers practically empty, there may be more vibration, but up to the present the propeller is a success."

The "Loongana" which is fitted with three Parson's Turbines, also had three Propellers dynamically balanced, and three statically balanced at the Naval Dockyards, The ones which were dynamically balanced show a great improvement in having less vibration. After these had been on a few months, they were changed to the statically balanced set for experimental purposes, and we at once noticed a considerable change in increased vibration. Unfortunately with the "Loongana" in the trade she is working on, considerable propeller damage takes place in the shallow parts of the Launceston River, and it is impossible to keep any propeller any length of time without damage and being put out of balance.

Yours faithfully,

(Sgd.) J. SMITH, Local Supt. Engineer.

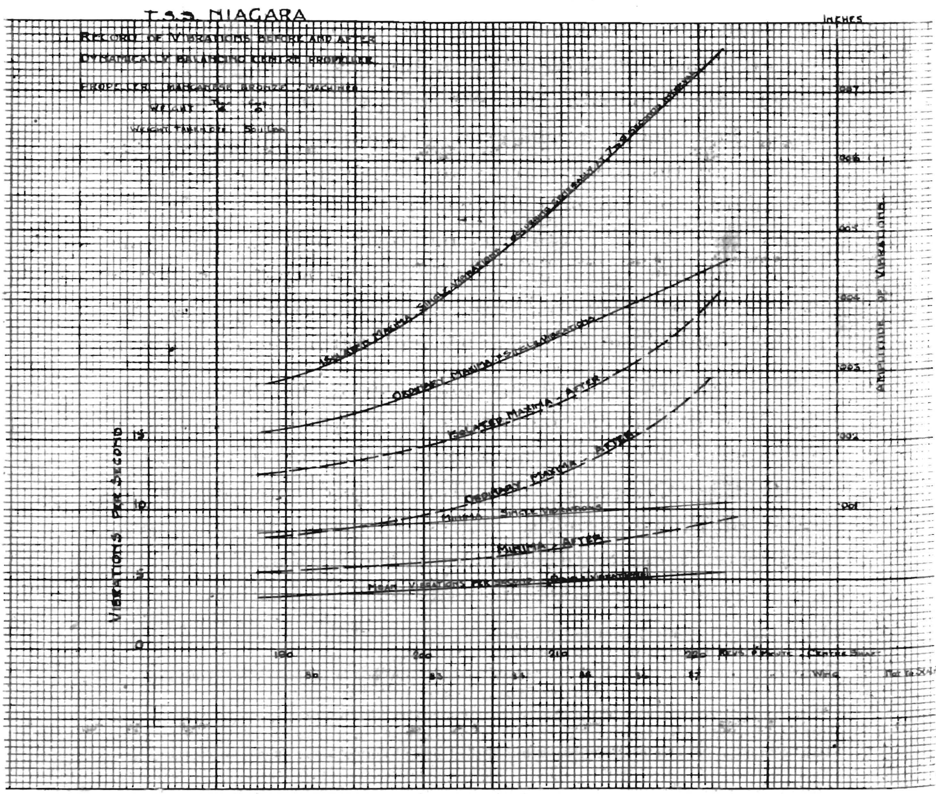

Fig. 13

The vibration records referred in the letter quoted have been analysed, and Fig. XIII. shows the results obtained from them, about which it may be observed that great difficulty was experienced in finding a suitable place in the ship where the recorder (vide Fig. 13 of my former paper) could give good readings, and it will be also noted that the amplitude of the vibration is very small.

All the propellers we have lately manufactured to be turbine driven have been put straight into the dynamical balancing machine, and we have found that it is quicker and cheaper than only balancing on a knife edge, and we have the further satisfaction of knowing that such propellers are in true running balance.

DISCUSSION.

Mr. J. C. Bradfield (Sydney University Engineering Association) said that it gave him great pleasure to be present and to move a vote of thanks to Mr. King-Salter for his interesting paper. Before doing so he would like to say that some weeks ago the University Engineering Society held a meeting and decided to come into the Institute of Engineers of Australia. The postal ballot was completed on Monday last, and the vote was unanimously in favor of coming into the Institution. This was the second combined meeting of the three resident Societies held in Sydney. The next one would be held under the auspices of the Sydney University Society. He believed it would be the last. It would be held the day after the Council held its meeting. He said:—In attempting to discuss Mr. King-Salter's carefully prepared paper, giving the results of further experiments in the dynamic balancing of rotating masses, one is handicapped in not having heard or read his previous paper.